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An experiment to measure learning when stimuli are presented through one or two channels showed that an auditory signal combined with a relevant picture--the two-channel cue summation condition--was superior to five other methods of communication, or "treatments." These other five were: one-channel visual only; one-channel auditory only; two-channel redundant, i.e., words presented audibly with simultaneous presentation of the same words visually; two-channel high similarity, i.e., two words presented audibly with simultaneous presentation of pictures of different objects of the same class; and two-channel low similarity, i.e., words presented audibly with simultaneous presentation of pictures of objects of a different class. Almost 250 seventh graders were stratified for intelligence and randomly assigned to the six treatments. Each treatment consisted of a stimulus series of 15 nouns, followed by 40 items from which the respondent had to select the original items. Statistical tests showed the cue summation condition to be superior to the redundant condition and the visual only condition to be superior to the auditory only condition. No other significant differe ces were found. (OH)

Technical Report No. 37

CUE SUMMATION IN MULTIPLE-CHANNEL COMMUNICATION.

By Werner Severin

Report from the Media and Concept Learning Project,
Bruce H. Westley, Principal Investigator

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

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PREFACE

This technical report is based upon the dissertation of Werner Severin. The examining committee consisted of Professors Bruce Westley (chairman), Steven Chaffee, Jack McLeod, and Harry Sharp.

One major program of the Wisconsin R and D Center for Cognitive Learning is Program 1 which is concerned with fundamental conditions and processes of learning. This Program consists of laboratory-type research projects, each independently concentrating on certain basic organismic or situational determinants of cognitive learning, but all united in the task of providing knowledge which can be effectively utilized in the construction of instructional systems for tomorrow's schools.

An important concern in the field of human learning is the optimal use of communication media. Researchers are actively providing empirical data upon which are built theories concerning information transmission in multiple-channel presentations. In his dissertation Mr. Severin observed the performance of seventh-grade pupils on a simple word recognition task in order to determine the relative effectiveness of providing auditory or visual cues or both combined to be either redundant or interfering cues. His results add to our knowledge of the conditions under which multiple-channel communication provides the maximum amount of information transmission.

Harold J. Fletcher
Director, Program 1

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ABSTRACT

Early findings tended to support the contention that when learning materials are presented in more than one channel or modality, more learning will result. More recent work has brought this view into question.

It was predicted on the basis of cue summation theory that, when cues to the same object are presented simultaneously in two modalities, more learning should result than when the same cues are presented in either modality alone, and that no such increase should occur when the cues are redundant. On the basis of interference theory, it was predicted that when contradictory cues are presented simultaneously in two modalities, a learning decrement should result.

Two hundred forty-six seventh graders were stratified on intelligence and randomly assigned to six treatments: (1) an auditory signal combined with a relevant picture (the cue summation condition), (2) auditory and visual signals presenting the same words simultaneously (the redundant condition), (3) the visual (print) signal alone, (4) the auditory (word) signal alone, (5) auditory combined with highly unrelated pictures, and (6) auditory with a more nearly related picture. (Treatments 5 and 6 were interference conditions.) Subjects were given a recognition task. Testing conditions were identical to presentation conditions.

As predicted, the cue summation condition was superior to the redundant condition and to both single-channel and both interference conditions. The more nearly related picture produced more interference than did the highly unrelated picture.

I

THE PROBLEM

It has long been an axiom of audio-visual education that more learning results when information is presented to a learner in two channels (or sense modalities) than when it is presented in one. Reviews of research literature on the subject in the 1950's tended to support this proposition (Hovland, 1954; Day and Beach, 1950; Hoban and Van Ormer, 1950). More recently Hartman (1961b), in a review of 30 studies involving channel comparisons, concluded that related material presented in two channels is more effective than the same material presented in one.

The studies reviewed, however, were, for the most part, carried out before 1940, and, as these reviews point out, there are serious flaws in the methodology employed in almost all of them. New work, carried out largely by the Travers group at the University of Utah, has raised serious questions about the validity of the two-channel "theory." A thorough review of the literature by Travers and his associates (1964) has raised doubts about the superiority of two-channel presentations, and the experimental work carried out by the Utah group (e.g. Van Mondfrans and Travers, 1964) has tended to support their position.

At the same time, theoretical models have been developed, the implications of which appear to be that in many circumstances cues presented in more than one modality simultaneously cannot effectively transmit more information than can be transmitted in one channel. Broadbent (1958) has presented such a model in general agreement with the position of Cherry (1953).

The primary question is whether redundant cues presented simultaneously in two modalities provide additional cues to the learner, thus leading to improved learning performance; provide no additional cues, thus not affecting learning; or tend to produce an interference effect, leading to a reduction in learning. ("Redundant" in this literature refers to the same cue presented in different channels.)

The interference hypothesis is by no means new. There has been a tendency, in fact, for an interference effect to be inferred when two-channel communications have proved to be less effective than one-channel communications. When Williams, Paul, and Ogilvie (1957) found that an auditory-only presentation was superior to a live speaker, they suggested that distracting cues surrounding the speaker must have produced interference. Kale, Grosslight, and McIntyre (1955) suggested that interference in the sound track might have reduced learning of foreign vocabulary in a two-channel learning situation. But these are post facto inferences, and none of these studies has tested the interference hypothesis directly.

Nor does Broadbent infer interference directly. His position is that when two cues arrive at a central information-processing mechanism simultaneously, they cannot be processed simultaneously; rather, since the higher mechanism is a one-channel system, one cue must be filtered out permitting only one cue to enter the higher processing mechanism at a time. He postulates a temporary storage mechanism. Thus the filtering process may tend to eliminate any advantage that might be gained by simultaneous presentation of redundant cues in more than one modality.

However, Travers interprets Broadbent as asserting that the effect may be one of interference under certain circumstances, notably when the information load is high: "If two or more messages with high information content are received through two different internal channels, the system may jam [Travers, 1964a, p. 38]."

Van Mondfrans and Travers presented a test of the hypothesis that "when redundant information is transmitted simultaneously through two sense modalities, more information is retained than when only one modality is involved [1964a, p. 744]." Stimulus materials were nonsense syllables, words presented singly, and words presented in sentences. Visual-only and visual-auditory presentations produced no differences in learning under any of these stimulus conditions. In the case of nonsense syllables, auditory-only was significantly inferior to both

visual-only and visual-auditory conditions, but there were no other differences. The conclusion was that "the use of two sensory modalities has no advantage over one in the learning of material that is redundant across modalities [p. 749]."

Jester and Travers (cited by Travers, 1964b, p. 376) varied rate of presentation of redundant materials and obtained a significant difference favoring the visual-auditory combination, but only at speeds in excess of 200 words per minute. This finding is of interest mainly because the Broadbent model would predict the opposite outcome.

All of these results are based upon work with entirely redundant materials. In the two-channel conditions, a word or nonsense syllable was presented visually and simultaneously the same word or nonsense syllable was pronounced. In conditions where the same cue is presented in different channels, Hartman (1961a, p. 25) had earlier questioned whether the results would be the same if different cues to the same referent were presented simultaneously in different channels.

Miller (1957) suggested to audio-visual educators that the "cue summation" principle might be employed to improve the teaching effectiveness of an audio-visual presentation, pointing out that increasing the number of cues available might, in effect, offer alternative cues to learners who might use different cues to help them make the proper discriminations.

> When cues from different modalities (or different cues within the same modality) are used simultaneously, they may either facilitate or interfere with each other. When the cues elicit the same response simultaneously, or different responses in the proper succession, they should summate to yield increased effectiveness. When the cues elicit incompatible responses, they should produce conflict and interference [p. 78].

Hartman and Travers have also pointed out the possibility that competing cues may cause distraction when they tend to elicit competing responses. But when do cues compete and interfere and when do they summate and produce gains ?

Hartman has suggested that pictorial presentation in the visual channel may be an instance of a different cue capable of eliciting the same response. Thus the Travers group may have overlooked an important point: that when redundant cues are added to the message there may be no gain because there are in fact no additional cues; but when nonredundant cues are added, there is the possibility that these act additively. In other words, totally redundant stimuli presented in two channels may produce no gain because they add no cues, but relevant cues in a second channel may increase effectiveness because they do add cues.

There is evidence for the "cue summation" position—evidence that visual material presented in the form of pictorial cues is superior to auditory-only presentations. Kale, Grosslight, and McIntyre (1955) found that a picture-word combination was superior to a word-word combination in producing learning of Russian vocabulary. Barrow and Westley (1959) found that television versions of a series of information programs were superior to radio versions in producing immediate recall; they also showed that concepts presented in the visual dimension (by such devices as film clips and still pictures) were more "salient" for their sixth-grade respondents than were the same concepts in the radio version. There is also some evidence that pictorial cues are more effective than words presented visually in producing paired-associate learning (Lumsdaine and Gladstone, 1958; Kopstein and Roshal, 1954).

Ketcham and Heath (1962) reported an experiment in which a relevant-cue two-channel presentation was compared with a single-channel presentation and with irrelevant cues. In their experiment the highest group mean was obtained when an auditory presentation was combined with relevant pictorial cues. A sound-only condition was next highest, followed by two irrelevant conditions—the sound combined with the visual presentation of geometric forms and sound combined with pictures unrelated to the narration. Although the single one-way analysis of variance was significant ($p < .01$), no tests of the significance of individual pairs of means was presented. This experiment did not, of course, test the cue summation hypothesis, since there was no redundant condition to compare with the relevant-cue condition.

Hartman's (1961a) experiments shed little light on the question. His audio-pictorial combination in every case yielded significantly lower learning than his single-channel conditions. However it is clear that he actually introduced an interference condition whenever he combined words and pictures. In every case names and pictures were arbitrarily combined and thus subjects had no prior association for the combination. There is no reason to expect unassociated cues to summate. Hartman's experiments utilized no cue summation condition at all; his audio-print condition was a redundant condition in our terms and his audio-pictorial condition was an interference condition, as he admits.

Travers, too, concludes that there is little or no

advantage to completely redundant material in two channels (except at very high speeds). His work, however, did not test the possibility that related cues added in a second channel would produce greater learning than redundant cues in the second channel—and greater learning than one channel alone.

This distinction between relevant cues and redundant cues is the key to the experiment reported here. Cue summation theory predicts that relevant cues should produce greater learning than redundant cues; that a relevant cue condition would be superior to a one-channel condition; and that a redundant cue condition should be no better than a one-channel condition.

It was further hypothesized that, when irrelevant or unrelated cues are presented in the second channel, loss in learning will result owing to interference.

Finally, a prediction based not on cue summation or interference but on previous empirical evidence was added to complete the design. This was to the effect that cues presented visually (words in print) would be superior to words presented audibly (words pronounced).

The empirical basis for this prediction is summarized by Hartman (1961b, pp. 237-8) when he says, "The print channel becomes more effective relative to the audio as the difficulty of the material for the subjects increases provided a fair degree of literacy is present." Berelson and Steiner (1964, p. 547) say, "In general, it appears that the more complex the material, the better print is from the standpoint of comprehension." Klapper (1960, p. 110) makes the same point. These conclusions are based on the empirical findings of Carver (1941), Corey (1934), Kay (1958), Larsen and Feder (1940), and Lumley (1933), among others. However, Hartman's (1961a) evidence is again inconclusive. The only difference he obtained between audio and print presentations favored print only when tested in the print condition. All other comparisons showed no difference. He did not vary task difficulty.

It is now possible to state the predictions in rank order form as in Figure 1. The rationale for each of these eight predicted relationships may be summarized as follows:

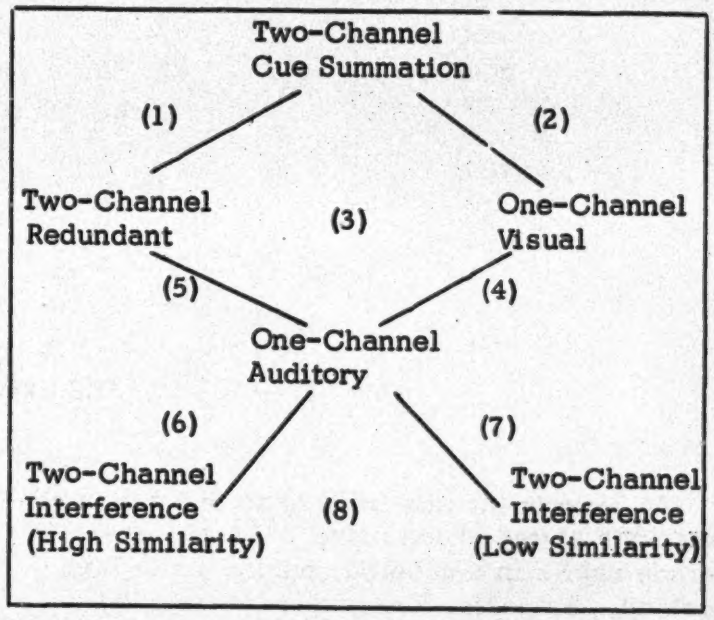

Figure 1

Predicted rank order comparisons. Higher position may be read as "greater than." Individual predictions are numbered.

The first three expectations are based on cue summation theory, which predicts (1) that the cue summation condition should be superior to the redundant condition, (2) that the two-channel summation condition should be superior to a single-channel (non-summation) condition, and (3) that there should be no difference between two non-summation conditions. Prediction 4 is based on empirical evidence and Prediction 5 follows from the above.

Predictions 6 and 7 state that competing cues simultaneously presented in two channels should produce less learning than either one-channel condition. The two treatments differed in the degree to which the pictured interference object differed from the word simultaneously pronounced. In the high similarity condition, the objects were drawn from the same general class; in the low similarity condition, they were drawn from different classes. While it appeared intuitively plausible that the high similarity condition would produce greater interference, such a prediction could not be made directly from cue summation theory and no relevant literature was found. Therefore Prediction 8 was given as one of no difference.

II

THE EXPERIMENT

An experiment was devised to test the predictions stated above using 246 seventh-grade pupils in a suburban public junior high school. Subjects were randomly assigned to six treatments after stratification for intelligence, using the Lorge-Thorndike Intelligence Test, 1957 version. Test scores were made available by the school. Incomplete intelligence test data and absentees reduced the total to 201, divided into groups ranging in size from 29 to 39. Mean Lorge-Thorndike scores were computed for each group. After an F test for heterogeneity of variance showed no significant differences in group variances (F equals 1.37, df 33 and 31), a t test between the highest and lowest group means was performed to test for differences between homogeneous means. No difference was found (Table 1). Subjects were randomly assigned to seating position.

MATERIALS

Stimulus materials were recorded—the auditory materials on auditory tape, the visual materials on 2 × 2 color slides—and all instructions were taped to assure uniform administration. To assure high quality and uniformity, the recording was done in the recording studios of WHA, the station at The University of Wisconsin.

To assure that the materials were appropriate to seventh-grade subjects and to assure minimal differences in prior learning, the referent objects chosen for the experiment were widely-known nature objects; using the Thorndike-Lorge Teacher's Word Book (1944), 42 were chosen whose names appear at least twice but not more than 10 times per million English words. The words chosen are listed in the Appendix. For photographic illustrations, color slides were made from uniform-size pictures taken from an illustrated nature book (Parker, 1952).

Each treatment consisted of a stimulus series of 15 names, followed by a recognition task which presented a list of 40 items from which the respondent was to select the ones which had been included among the 15 original items. Thirteen of the 15 items were actually used. The position of the critical items in the 40-item test was randomly determined. The 15 stimulus items were presented at intervals of 3 seconds. In the test condition the interval between items was also 3 seconds. However, as the time required to change the slides was 1 1/2 seconds, the actual exposure time was approximately 1 1/2 seconds.

Treatment groups were assembled in classrooms in seats arranged in five rows of eight seats each. It was not possible to arrange seating at exact intervals because of fixed seats in some of the classrooms used. However, the differences appeared to be minor.

Visual materials were projected by Kodak Carousel 570 slide projectors onto a 60 × 60-inch screen located forward from the middle positition of the front row seats. The projector was placed just behind the last row of seats, and the screen was located so that the image exactly filled it from side to side. Thus, the image size was identical in all conditions. Auditory materials were presented using UHER 722 tape recorders with the speaker located just to the right of the screen. The synchronization between the audible word and the projected word was accomplished by inaudible signals recorded on the tape, which automatically changed the slides synchronously with the auditory signal.

PRETEST

Materials and equipment were pretested with a medium-level seventh-grade class in another junior high school. Only the audio-word treatment was pretested with the 27 pupils available. The materials and equipment worked well and no revisions were deemed necessary.

It should be noted that the testing materials employed the same media as the presentation

Table 1

Lorge-Thorndike Intelligence Test Means, Standard Deviations and Variance Estimates for Each Treatment Group

Group No.	N	Mean	Standard Deviation	Variance Estimate
1	33	110.88	12.72	161.67
2	33	111.09	12.27	150.46
3	34	109.47	11.06	122.26
4	29	110.03	12.30	151.18
5	39	109.64	12.90	166.50
6	32	110.66	12.94	167.52

situations. This was done because previous work (Irwin and Aronson, 1958; Hartman, 1961a) has shown that the medium used for testing may affect differences unless the testing medium is identical to the presentation medium.

ADDITIONAL INDIVIDUAL DIFFERENCES

In addition to the Lorge-Thorndike Intelligence Test scores, the school system made available to the research team data from the Iowa Tests of Basic Skills. The data included four subtest scores and a composite score, all given in percentiles on the basis of local and national norms. The four subtests are: (1) Language Skills—vocabulary, spelling, capitalization, punctuation, and usage; (2) Reading Comprehension—recognizing factual details and relationships, identifying the main idea in a passage, developing skill in organization of ideas, and evaluating what is read; (3) Work Study Skills—using graphic materials, reference materials, tables and maps; and (4) Arithmetic Concepts. Evaluations have been given by Freeman (1959), Knief and Stroud (1959), Garlock and Harsh (1960), and Finley (1963).

These scores were recorded in the belief that they might provide clues to individual differences and their interactions, if any, with treatments, although no hypotheses regarding these variables were stated.

The six groups, then, were given the following treatments:

Two-channel cue-summation condition: words presented audibly with simultaneous presentation of pictures of the same objects.

Two-channel redundant condition: words presented audibly with simultaneous presentation of the same words visually.

One-channel visual only: words presented visually only.

One-channel auditory only: words presented audibly only.

Two-channel high similarity: words presented audibly with simultaneous presentation of pictures of different objects of the same class.

Two-channel low similarity: words presented audibly with simultaneous presentation of pictures of objects of a different class.

III

RESULTS

Group means for the six experimental conditions are shown in Table 2. It may be seen that the means are in the predicted order in every case where predictions were made. To determine the significance of pairs of treatment means, an F test for homogeneity of variance and subsequent t tests were performed. The results are given in Table 3. Here it is clear that the two main predictions are borne out by significant differences: the cue summation condition was superior to the redundant cues condition and visual was superior to auditory. However, the predicted superiority of the one-channel auditory condition over the two-channel low similarity condition did not result.

To test for the possibility that individual differences interact with treatments, analyses of variance were performed for the Lorge-Thorndike Intelligence Test scores, the four sub-scores and the composite score on the Iowa Tests of Basic Skills, and seating position. The results of these tests are reported elsewhere (Severin, 1967) and consequently only two will be reported here. The results in all cases were the same—no significant interactions were obtained.

The Work-Study scores were of interest because it appeared possible that the skills in using visual materials, presumably measured by the subtest, might be related to the effectiveness of the visual treatments. The results are shown in Table 4. They indicate again, of course, that the treatment means were significantly different. They also indicate that the Work-Study scores were significantly different but the relationship is a curvilinear one—the medium work-study group had the highest recognition test mean. The important result, however, is that there was no signifi-

Table 2

Means and Standard Deviations for Recognition Scores by Treatment

Treatment	N*	Mean	Standard Deviation
1. Two Channel Cue Summation	33	38.24	1.75
2. Two Channel Redundant	33	36.12	2.34
3. One Channel Print Only	34	34.94	4.49
4. One Channel Audio Only	30	30.17	6.26
5. Two Channel Low Similarity	39	29.59	5.50
6. Two Channel High Similarity	32	26.90	6.13

*Included in Group 4 are data from one S for whom individual difference scores were incomplete. This accounts for differences in Ns for this group in previous and subsequent tables.

cant interaction between Work-Study scores and treatments.

Following the reasoning that reading skills may influence the results—for example, that persons of high reading skill would learn relatively more from the visual-verbal treatments—possible interaction between reading comprehension and treatments was investigated. The results are shown in Table 5. A significant overall effect of reading comprehension was found (and the relationship this time was a direct one) but again no significant interaction.

When it appeared that the individual differences, including intelligence, were not affecting the basic results reported in Table 2, a linear ranks test (Page, 1963) was computed for all the data available. The results are reported in the dissertation (Severin, 1967) but may be summarized here: in all cases, a significant L was obtained, indicating that the rank order obtained in the first-order analysis persisted through all the individual differences measured, thus further confirming the original predictions.

Table 3

F Ratios for Homogeneity of Variance and Multiple t Tests for Treatment Means, for Independent Samples, Unequal Ns

Treatments	Variance F Ratio	F test	t	Cochran's t	df	Significance
1 and 2	1.648	n.s.	3.22	-	64	.005 1-tailed
2 and 3	3.668	sig.	1.35	1.70	65	n.s.
3 and 4	1.951	n.s.	3.48	-	62	.0005 1-tailed
4 and 5	1.297	n.s.	.40	-	67	n.s.
5 and 6	1.242	n.s.	1.94	-	69	.06 2-tailed

Table 4

Mean Recognition Scores and Analysis of Variance for Treatments by Work-Study Groups

Work-Study Groups	n	Treatments 1	2	3	4	5	6
High	59	38.78	36.46	31.25	28.43	30.15	29.78
Medium	72	38.67	36.25	36.07	33.54	31.10	28.18
Low	70	37.42	35.38	36.08	27.00	28.19	23.58
n		33	33	34	30	39	32

Analysis of Variance:

	SS	df	F	
Rows	428.38	2	10.50	$p < .01$
Columns	3279.42	5	32.17	.01
R × C	229.16	10	1.12	(ns)
Within	3732.25	183		

Table 5

Mean Recognition Scores and Analysis of Variance for Treatments by Reading Comprehension

R-Compre Groups	n	·1	2	3	4	5	6
High	61	38.33	36.07	32.50	31.00	32.44	29.55
Medium	70	38.67	35.75	36.36	32.09	29.86	25.10
Low	69	37.75	36.86	36.18	26.17	27.75	25.91
n		33	33	34	29	39	32

Analysis of Variance:

	SS	df	F	
Rows	201.06	2	4.91	p < .01
Columns	3330.85	5	32.57	.01
R × C	389.39	10	1.86	(ns)
Within	3722.20	182		

IV

DISCUSSION

As predicted from cue summation theory, the combination of an auditory signal with a visual presentation providing a different but related cue to the stimulus object was more effective in producing recognition than combination with a visual presentation of the same cue—the redundant condition. In addition, cue summation theory was supported in the finding that the redundant two-channel condition was no better than the visual (print-only) condition alone. The fact that the redundant and print-only conditions were superior to the auditory condition was to be expected because the superiority of visual word cues over auditory word cues had been established by previous studies.

In addition it was found that irrelevant cues in the visual presentation produced substantial losses in recognition, as might be expected on the basis of an "interference" hypothesis. Finally it turned out that the more the irrelevant visual cues differed from the auditory cues, the smaller the loss. While in line with common sense and various findings of learning theory, this outcome had not been predicted.

These findings are in accord with but go beyond those of Travers and his associates who also found that redundant cues presented in different channels simultaneously yield no improvement over single-channel presentations. At the same time, the findings support the suggestion by Miller (1957) that, when cues added in second channel are related to and not merely redundant with the cues of the first channel, a learning increment should result. The findings presented here suggest that such added cues tend to "summate" where redundant cues do not.

It was also shown that the strength of the cue summation effect and its opposite—the interference effect that results when cues to different objects are presented simultaneously—is such that it tends to occur at all levels of intelligence and of communication skills such as work-study skills and reading comprehension.

It should be emphasized, of course, that these results may be directly applied only to the conditions which obtained in this experiment. They do not necessarily generalize to other than a recognition task. This task was deliberately chosen as the best means of testing the information attained under varying channel and message conditions but other learning tasks may produce other results. The finding that words presented visually as print and words presented audibly have different effects for these particular tasks and groups is especially vulnerable to learning conditions; an easier or harder task or less literate subjects could obviously affect the results.

At the same time three findings in the present data do not support Travers' interpretation of his own and previous findings that when two channels are used the subjects merely ignore one channel and concentrate on the other: (1) additional relevant cues produced greater recognition learning than additional redundant cues; (2) additional relevant cues produced more recognition learning than either of the single-channel conditions; and (3) there were significant differences between the one-channel visual condition and both interference conditions. The significant difference between the two interference conditions may, however, present support for Travers' interpretation; less interference with recognition from the highly irrelevant cues than from the less highly irrelevant cues could have been the result of the subjects' learning to ignore misleading information in the visual channel. This interpretation is strengthened by the finding of no significant difference between the highly irrelevant cue condition and the audio-only condition.

These results suggest that multi-modality stimulus materials may be capable of producing increments in learning under certain conditions; they also suggest what one of these conditions might be: use of the second channel to carry additional related cues rather than simply redundant cues.

APPENDIX

WORDS USED FOR STIMULUS MATERIALS AND FOR TESTING

Stimulus Group

antelope	cardinal	tulip
bison	hummingbird	catfish
coyote	warbler	shrimp
moose	bluebell	bullfrog
oriole	orchid	firefly

Test Group

antelope	woodpecker	poppy
alligator	goldfinch	tulip
bison	wren	catfish
hippopotamus	hummingbird	eel
moose	pheasant	goldfish
opossum	martin	lobster
raccoon	blackbird	shrimp
weasel	warbler	bullfrog
martin	aster	chameleon
cardinal	bluebell	tortoise
carbird	cactus	newt
chickadee	daffodil	dragonfly
crane	orchid	earthworm
		firefly

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